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Journal:	*Applied Economics*
Manuscript ID:	APE-05-0089.R1
Journal Selection:	Applied Economics
JEL Code:	C23 - Models with Panel Data < , Q50 - General < , O10 - General <
Keywords:	Environmental Kuznets Curve, smooth transition regression, threshold

Editorial Office, Dept of Economics, Warwick University, Coventry CV4 7AL, UK

Environment and development: Is there a Kuznets curve for CO_2 emissions? ♣

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Abstract

This paper re-examines the relationship between growth in per capita income and environmental degradation using econometric techniques appropriate for smooth transition regressions with panel data. This is a more intuitive and flexible methodology than the polynomial models widely used in the literature, and it can reconcile some of the mixed results found previously. The methodology is applied to carbon dioxide emissions from non-OECD countries over the period 1971-1997. Although there is no evidence of environmental Kuznets curve (EKC), we find two regimes, namely a low-income regime where emissions accelerate with economic growth and a middle to high-income regime associated with a deceleration in environmental degradation.

Keywords: Environmental Kuznets Curve, panel smooth transition regression, threshold.

JEL: C2, O1.

♣ We are grateful to Marzio Galeotti for providing us the data and to Denise Osborn for her helpful comments. We also thank an anonymous referee for helpful comments which greatly improved the paper. Any remaining errors are exclusively ours.

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1. Introduction

The hypothesis of an inverted U-shaped relationship between income growth and environmental degradation, the so-called Environmental Kuznets Curve (EKC), has been the subject of intense investigation and yet no consensus has been reached as to its validity, especially for developing countries.[1] Although it is essentially an empirical finding, some papers have also derived the EKC theoretically.[2] They obtain an inverted 'V-shaped' curve where pollution increases with income until certain level of income, described as the "income turning point", is reached, after which pollution decreases with further growth. On the empirical front, a number of papers have studied the robustness of the basic quadratic model to alternative functional forms, with the semi-parametric techniques proposed by Millimet, List and Stengos (2003) being the last econometric tool used to test for the existence of the EKC.[3]

The purpose of this paper is to empirically test for the inverted-V model for developing countries by employing econometric techniques appropriate for regime-switching models with panel data. This family of models seem a more intuitive way to test the EKC as they assume there exist different regimes and allow for the emission-income relationship to depend on the prevailing regime (determined by the level of income) at any given observation. As some income threshold is passed, the economy smoothly changes from one regime to another. The smooth transition property is appealing because it allows for a richer structure than the inverted-V model during the

[1] See among others, Grossman and Krueger (1993), Shafik and Bandyopadhyay (1992), Panayotou (1993), Shafik (1994), Selden and Song (1994), Grossman and Krueger (1995), Holtz-Eakin and Selden (1995), de Bruyn et al. (1998), Wang et al. (1998), Millinet et al. (2003).
[2] See for example, John and Pecchenino, 1994, Stokey, 1998, Jaeger, 1998, Jones and Manuelli, 2001. Levinson (2002) provides a review of the empirical as well as the theoretical literature.
[3] The semiparametric techniques has not yielded conclusive results either. While Millimet, List and Stengos (2003) quite firmly conclude that an EKC exists for sulphur dioxide and nitrogen oxide for US states, using such semi-parametric estimation on a panel of countries Bertinelli and Strobl (2005) can not reject a linear relationship between per capita income and sulphur and carbon dioxide emissions.

transition phase. While the theoretically derived inverted V-model predicts an abrupt change in the slope of the income-emission relationship, our model allows for a smooth inverted-V or *inverted-U* relationship. Moreover, we empirically justify our methodology by showing that the quadratic and the cubic polynomial models widely used in the literature are specific cases of the more general regime-switching model we propose.

The methodology is applied to a panel dataset of carbon dioxide emissions in 77 developing countries over the period 1971-97. The study of the EKC for developing countries is interesting because it is arguable that the factors giving rise to the EKC in developed countries can also apply to developing economies. In effect, one of the underlying reasons for the EKC is that developed countries 'export' environmental degradation by relocating manufacturing activities to less developed countries while the service sector (which is environmentally cleaner) gains relative importance --e.g. Arrow et al. (1995), Stern et al. (1996). This line of argument would then imply that there is a limit to environmental improvement as there would be no countries to which today's developing countries could export the environmentally dirty activities as they become wealthier.

Although we do not find an inverted U-shaped income-pollution relationship for the period studied, our results show that environmental degradation decelerates as low-income countries grow. Our findings can also reconcile some of the mixed results previously obtained in the literature. To be sure, the insignificance of the quadratic term (that leads one to reject the existence of an EKC) and/or the existence of an EKC with well out-of-sample turning points are findings consistent with the existence of two regimes in the income-pollution relationship, namely one with a positive and relatively steep slope and another with still a positive but flatter slope. Finally, it is worthwhile to stress the importance of the finding of a deceleration in the emissions of carbon dioxide, a major determinant of the greenhouse gas implicated in global warming. While the physical effects of local pollutants such as sulphur dioxide or nitrogen oxide are conspicuous and can be accounted for by only domestic activity, the effects of carbon dioxide are far-reaching and cause an international externality.[4] Thus the incentives to abate carbon emissions are clearly undermined by the free-rider problem, what makes our results particularly interesting.

The paper is organized as follows. Section 2 summarizes the methodology. Section 3 discusses the estimation methodology as well as the test for the regime switching effect. The results are presented in section 4 while section 5 concludes.

2. Methodology

One of the most prominent regime-switching models is the smooth transition regression (STR) model promoted by Teräsvirta and Anderson (1992) and Granger and Teräsvirta (1993) in the macroeconometrics literature. González et al. (2005) introduced this approach to panel STR models (PSTR) while Aslanidis and Xepapadeas (2006) considered PSTR in the analysis of the emission-income relationship for SO_2 and NO_x in U.S. states. Here we consider a generalization of the panel smooth transition regression (PSTR) model that permits the possibility of asymmetry in the transition mechanism, allowing for different rates of entry and exit from the transition phase. Consider the smooth transition regression (STR) model with fixed effects

[4] The negative externalities arising from carbon dioxide and sulphur emissions are markedly different. While sulphur causes immediate and severe damage to the health of the residents near the pollution sources, carbon dioxide itself is non-toxic to humans but causes global warming in the long run. Furthermore, while desulfurization is technically feasible, there is no practical technology to abate carbon dioxide without reducing fossil energy use.

$$P_{it} = \mu_i + \beta_1 Y_{it} + (\beta_2 Y_{it}) F(Y_{it}) + u_{it}, \quad i = 1,\dots,N \,;\; t = 1,\dots,T \quad (1)$$

where P_{it} is the log of per capita carbon dioxide emissions in country i in year t, Y_{it} is the log of per capita GDP in country i in year t, $\beta \equiv (\beta_1, \beta_2)'$ is the parameter vector to be estimated, μ_i captures country-specific effects and u_{it} is an error term. The function $F(Y_{it})$ is the transition function which is assumed to be continuous and bounded by zero and unity and Y_{it} is the transition variable. Another way of writing (1) is

$$P_{it} = \begin{cases} \mu_i + \beta_1 Y_{it} + u_{it} & F = 0 \\ \mu_i + (\beta_1 + \beta_2) Y_{it} + u_{it} & F = 1 \end{cases}$$

An environmental Kuznets curve exists if $\beta_1 > 0$ and $\beta_1 + \beta_2 < 0$. In words, emissions increase with income up to some threshold level of income, after which they are reduced with further growth. Values of $F(Y_{it})$ between 0 and 1 define situations where the relationship is a mixture of the two regimes. That is, the emission-income relationship displays a smooth inverted V-shaped path with a transition phase, which could be slower or faster, from one regime to another.

We consider the generalized logistic function known as the Burr-type function (Burr, 1942) for the transition function:[5]

$$F(Y_{it}; \gamma, c, k) = \left(1 + \exp(-\gamma (Y_{it} - c))\right)^{-k} \qquad \gamma > 0,\; k > 0 \quad (2)$$

The parameter c is a location parameter but, unlike the symmetric logistic function, it can not be interpreted as the threshold between the two regimes. When asymmetry is

[5] See also Sollis, Leybourne and Newbold (1999) and Lundbergh and Teräsvirta (2006).

allowed for, the turning point becomes $Y^{threshold} = c - \gamma^{-1}\ln(2^{\frac{1}{k}} - 1)$.[6] The parameter γ determines the smoothness of the change in the value of the function and thus the speed of the transition from one regime to the other. When $\gamma \rightarrow \infty$ the transition between regimes is abrupt and then the STR model collapses to a threshold model. The parameter k is the asymmetry parameter. The generalized logistic function is skewed to the left if $0 < k < 1$ and right-skewed if $k > 1$, while the case $k = 1$ corresponds to the (symmetric) logistic function. The asymmetry property adds flexibility to the model allowing for entry and exit from the transition phase at different rates. Finally, identification requires $\gamma > 0$ and $k > 0$.

3. Estimation and testing of the regime-switching effect

3.1 Nonlinear least squares estimation

The parameters $\theta = (\beta_1, \beta_2, \gamma, c, k)'$ of the STR model in Eq. (1) are estimated by nonlinear least squares (NLS), which is equivalent to maximum likelihood estimation in the case of normal errors. We assume that the model satisfies the necessary regularity conditions discussed in González et al. (2005) for the consistency and asymptotic normality of the estimators. We first eliminate the country fixed effects μ_i by removing country-specific means and then apply NLS to the transformed data.

While eliminating fixed effects using the within transformation is standard in linear panel data models, the model under consideration calls for a more careful treatment. Note that when we take means in Eq. (1) we obtain

$$\overline{P}_i = \mu_i + \beta_1 \overline{Y}_i + \beta_2 \overline{W}_i(\gamma, c, k) + \overline{u}_i \tag{3}$$

[6] This value is obtained by setting $F(Y_{it}; \gamma, c, k) = 0.5$.

where $\bar{P}_i, \bar{Y}_i, \bar{W}_i(\gamma,c,k)$ and $\bar{u}_i$ are country means, with $\bar{W}_i(\gamma,c,k) = T^{-1}\sum_{t=1}^{T} Y_{it} F(Y_{it};\gamma,c,k)$. Subtracting (3) from (1) yields

$$\tilde{P}_{it} = \beta'\tilde{Y}_{it}(\gamma,c,k) + \tilde{u}_{it}$$

where $\tilde{P}_{it} = P_{it} - \bar{P}_i$, $\tilde{Y}_{it}(\gamma,c,k) = (Y_{it} - \bar{Y}_i, Y_{it}F(Y_{it};\gamma,c,k) - \bar{W}_i(\gamma,c,k))'$, $\beta = (\beta_1, \beta_2)'$ and $\tilde{u}_{it} = u_{it} - \bar{u}_i$. Notice that the transformed element $Y_{it}F(Y_{it};\gamma,c,k) - \bar{W}_i(\gamma,c,k)$ depends on (γ,c,k) through both the levels and the country means. For this reason, $Y_{it}F(Y_{it};\gamma,c,k) - \bar{W}_i(\gamma,c,k)$ needs to be recomputed at each iteration in the NLS optimization routine.

The estimation is done by minimizing the concentrated sum of squared errors (4) with respect to (γ,c,k) by NLS

$$LF(\gamma,c,k) = \sum_{i=1}^{N}\sum_{t=1}^{T}\left(\tilde{P}_{it} - \hat{\beta}'(\gamma,c,k)\tilde{Y}_{it}(\gamma,c,k)\right)^2 \quad (4)$$

where $\hat{\beta}'(\gamma,c,k)$ is obtained from (4) by ordinary least squares at each iteration in the nonlinear optimization routine.

An issue that deserves special attention is the selection of starting values for the NLS estimation. In order to obtain sensible initial values we carry out a three-dimensional grid search using 50 values for γ (1 to 50), 40 values for k (0.1 to 4) and at least 300 equally spaced values of c within the observed range of the transition variable. This dense grid search procedure ensures that the values of the transition function contain enough sample variation for each choice of γ, c and k. The model with the minimum residual sum of squares (RSS*)* value from the grid search is used to provide initial estimates of γ, c, k and of the coefficient parameters. Finally, the model is re-estimated by NLS.

3.2 Testing for the STR effect

Before estimating the STR model it is important to determine whether the regime-switching (STR) effect is statistically significant. The test of the regime-switching effect in the STR model (1) can be carried out in two ways, either by testing $H_0^{\gamma}: \gamma = 0$ or by testing $H_0^{\beta_2}: \beta_2 = 0$. In both cases the test is non-standard because under the null hypothesis, the model contains unidentified nuisance parameters. More specifically, (β_2, c, k) are not identified under H_0^{γ} and similarly (γ, c, k) are not identified under $H_0^{\beta_2}$. This is the so-called 'Davies' problem (see Davies, 1977, 1987). We follow Luukkonen et al. (1988) and test for the regime-switching effect as $H_0: \gamma = 0$. To circumvent the identification problem, we approximate the generalized logistic function using a Taylor series expansion around $\gamma = 0$. The first and second order approximations take the forms

$$F \approx \delta_0 + \delta_1 Y_{it}$$

and

$$F \approx \delta_0 + \delta_1 Y_{it} + \delta_2 Y_{it}^2$$

where $\delta_0 = F_{\gamma=0}$, $\delta_1 = F'_{\gamma=0}$, $\delta_2 = 0.5F''_{\gamma=0}$ are constants. Substituting them into (1) yields

$$P_{it} = \mu_i + \beta_1 Y_{it} + (\beta_2 Y_{it})(\delta_0 + \delta_1 Y_{it}) + u_{it}^*$$

and

$$P_{it} = \mu_i + \beta_1 Y_{it} + (\beta_2 Y_{it})(\delta_0 + \delta_1 Y_{it} + \delta_2 Y_{it}^2) + u_{it}^*$$

where the disturbance term u_{it}^* includes the remainder of the approximation. Rearranging terms one gets

$$P_{it} = \mu_i + \theta_1 Y_{it} + \theta_2 Y_{it}^2 + u_{it}^* \qquad (5)$$

and

$$P_{it}=\mu_i+\theta_1 Y_{it}+\theta_2 Y_{it}^2+\theta_3 Y_{it}^3+u_{it}^* \tag{6}$$

where $\theta_1 \equiv (\beta_1+\delta_0\beta_2)$, $\theta_2 \equiv \delta_1\beta_2$ and $\theta_3 \equiv \delta_2\beta_2$. Thus, testing the significance of the regime-switching effect amounts to testing $H_0{:}\theta_2=0$ in (5) and $H_0{:}\theta_2=\theta_3=0$ in (6). Standard asymptotic inference can be used to test the null hypothesis since Eq. (5) and (6) are linear in parameters.[7] The resulting test statistics from Eq. (5) and Eq. (6) are asymptotically distributed as χ_1^2 and χ_2^2.[8]

As it turns out, equations (5) and (6) are the quadratic and cubic functions of the levels of income widely used in the environmental Kuznets curve (EKC) literature as benchmark econometric specifications. Therefore, the regime-switching model of which the above auxiliary regressions are special cases is a more flexible specification with which to explore the emission-income relationship.

4. Empirical results

The data used in this study comes from the International Energy Agency (IEA). Table 1 reports some descriptive statistics. There are 2079 annual observations for CO_2 emissions from 77 non-OECD countries over the period 1971 to 1997. National income is measured by per capita GDP (in 1990 US dollars on a PPP basis) and comes from the World Bank.

Our first step is to test whether there is a statistically significant regime-switching (STR) effect by estimating the auxiliary regressions (5) and (6). Table 2 (bottom row) shows the p-values of the test, which strongly rejects the null hypothesis of linearity.

[7] González et al. (2005) discuss the assumptions necessary to obtain consistent and asymptotically normal estimators.

[8] It is worth mentioning that although this test is designed to test for STR effects it is also sensitive to other types of regime-switching effects such as the (abrupt) threshold effect -Luukkonen et al. (1988).

The reported *p*-values are 1.2×10^{-12} and 1.1×10^{-13} for Eq. (5) and (6) respectively, what implies a strong regime-switching behaviour. Table 2 also reports the estimated PSTR model, a logarithmic transformation of Eq. (1) with country fixed-effects and a time trend that we allow to vary across regimes as well.[9] The results yield a threshold at a per capita GDP of \$8,147, which divides the sample into two broad regimes: Regime 1 with low-income country-year observations and middle to high-income observations in Regime 2. The estimated model suggests that CO_2 emissions increase relatively fast during the early stages of economic development; this pattern smoothly changes around the income level of \$8,147 and thereafter emissions increase with growth at a lower rate. Figure 1 shows the shape of the estimated generalized logistic function versus the transition variable (log GDP). Regimes with low-income country-time observations (for which *F*(GDP) = 0) and middle to high-income observations (for which *F*(GDP) = 1) are identified together with a transition phase from one regime to the other. It is worth noting that the transition phase includes a substantial number of observations, while there are only few observations in regime 2 when *F*(GDP) = 1.[10] This is most likely due to the large heterogeneity among countries.

Compared to previous studies on carbon dioxide emissions, our findings are in line with those in Galeotti, Lanza and Pauli (2006) which, employing a Weibull functional form, obtain a concave pattern with no reasonable turning-point for non-OECD countries. On the other hand, at first sight our results seem at odds with some of the studies based on the quadratic model. For instance, using a panel of 149

[9] The time trend takes values 1,2,…,27. Alternatively to using a time trend, we included time fixed-effects intended to account for time-specific effects common to all countries. The results, available from the authors upon request, showed the time effects to be positive and increasing over time, that is, they displayed a trend. Therefore, we included the time trend instead of time fixed-effects.

[10] Although the convention is to consider that all the observations for which the transition function *F*(GDP) <0.5 belong to Regime 1 and those for which *F*(GDP)>0.5 are part of Regime 2, some stricter interpretations suggest that only those observations for which *F*(GDP) = 1 should be considered in Regime 2. If this alternative interpretation is adopted, then the number of observations in Regime 2 is arguably small.

countries (developed and developing countries) for the period 1960-90, Shafik (1994) finds that carbon emissions do not improve with rising income since the linear model has virtually all the explanatory power. Holtz-Eakin and Selden (1995) estimate a quadratic polynomial model and show some evidence of EKC for a panel of 130 countries (developed and developing countries) for 1951-1986, but their estimated turning point occurs at a very high level of per capita income. However, our results are not necessarily in contradiction with those findings. If the relationship between economic growth and pollution is governed by a 2-regime model where pollution increases with income in both regimes, but at a diminished rate in the second one, it is not surprising for the more restrictive quadratic model to deliver either an insignificant coefficient on the quadratic income term or well out-of-sample turning points.

The coefficient on the time trend, which is highly significant, is positive and becomes larger as income increases. This result has been found in other papers as well, such as Lantz and Feng (2005) which obtain a positive coefficient on a quadratic time trend term for Canada, or Shafik (1994) which finds a monotonic relationship between the time trend and various measures of environmental degradation.[11] The time trend captures exogenous or Hicks-neutral technological change, whereas the endogenous technological change is embodied in the coefficient of income. Thus, the increase in the coefficient of the time trend suggests that time-dependent technological innovations change investment rates in such a way that the demand for fossil fuel increases leading to a degradation in the environment.

Given the large heterogeneity among countries, notably in income levels, we perform some robustness checks by eliminating the countries at the extremes of the

[11] However, the literature has also reported opposite results concerning the effect of time-dependent technological changes. See for example, Talukdar and Meisner (2001) and Bruvoll and Medin (2003).

income distribution.[12] That is, we remove the 5% richest and 5% poorest countries over the sample period. The results, reported in Table 3, are qualitatively similar to those of Table 2. The turning point is found at a slightly higher per capita income -- \$9,912 as opposed to \$8,147. As before, the time trend effect is positive and gets stronger with income growth. By contrast, the transition function is qualitatively different from the previous estimation. As Figure 2 shows the transition function is now steeper what implies a faster switch between regimes. More importantly, the extreme value of the transition function, when F(GDP) = 1, has now a considerable number of observations. This is consistent with our previous conjecture that the large heterogeneity of countries reflects on a long estimated transition phase.

5. Concluding remarks

This paper re-addresses the pollution-income path or EKC from a different perspective. A regime-switching model that allows for a smooth transition between regimes is developed. The basic idea underlying this model is that when some income threshold is passed, the economy moves to another regime where the emission-income relationship is qualitatively different from that of the old regime. This framework is more intuitive and flexible than the quadratic or cubic polynomial models previously used in the literature. Furthermore, a regime-switching model can reconcile some of the previous mixed results obtained with the polynomial (quadratic and cubic) models. If the relationship between economic growth and pollution is governed by a 2-regime model with pollution increasing with income in both regimes but at a

[12] There are alternative and more sophisticated ways to account for the heterogeneity of countries. Using a pooled mean group estimator, Martinez-Zarzoso and Bengochea-Morancho (2004) allow for slope heterogeneity across countries in the short run while impose restrictions in the long run and test for their validity.

diminished rate in the second regime, it is not surprising for the more restrictive quadratic model to deliver an insignificant coefficient on the quadratic income term or well out-of-sample turning points. Although we do not find evidence of an environmental Kuznets curve (EKC), our results show a deceleration of emissions as low-income countries grow. Given the global negative externalities associated to carbon dioxide emissions this result is not negligible.

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Table 1: Summary statistics

CO_2		*Per capita GDP*	
Mean	*3.7823*	*Mean*	*4,766*
Standard deviation	*7.4901*	*Standard deviation*	*5,036*
Maximum	*54.849*	*Maximum*	*38,437*
Minimum	*0.0162*	*Minimum*	*227*
Estimation period 1971-1997			
# observations 2079			
# countries 77			

Notes: Non-OECD countries. *CO_2* emissions come from the International Energy Agency (IEA) and per capita GDP (in 1990 US dollars on a PPP basis) from the World Bank.

Table 2: PSTR model for *CO_2* emissions (All non-OECD countries)

Fixed-country effects

$$CO_2 = \underset{(16.08)}{0.646} * GDP + \underset{(8.494)}{0.008} * t + (\underset{(-9.208)}{-0.122} * GDP + \underset{(12.17)}{0.041} * t) * F(GDP)$$

Classification of regimes

Regime 1
$CO_2 = 0.646*GDP + 0.008*t$, when $F(GDP) = 0$
Regime 2
$CO_2 = 0.524*GDP + 0.049*t$, when $F(GDP) = 1$

Location parameter	Smoothness	Asymmetry
$\hat{c} = 8.470$	$\hat{\gamma} = 3.560$	$\hat{k} = 5$
(85.92)	(4.731)	(.)

Implied threshold
$Y^{threshold} = 9.005$ (antilog \$8,147)

R-sq = 0.9701

Regime switching (STR) effect *p*-value

Regression 5 (*GDP* squared)	1.2×10^{-12}
Regression 6 (*GDP* squared & cubed)	1.1×10^{-13}

Notes: The model is estimated by NLS conditioning on the value of *k*. Since the joint estimation of γ and k turned out to be very difficult (the algorithm did not converge) we followed the recommendation in Teräsvirta (1994) and conditioned the NLS estimation on one of the parameters (e.g, *k* was set to the value of 5 which was obtained from the grid search). Values in parentheses are t-ratios. The model is estimated in logs.

Table 3: PSTR model for CO_2 emissions (Non-OECD countries excluding the 5% richest and the 5% poorest countries)

Fixed-country effects

$$CO_2 = \underset{(13.80)}{0.460}*GDP + \underset{(12.34)}{0.012}*t + (\underset{(-9.809)}{-0.102}*GDP + \underset{(11.00)}{0.051}*t)*F(GDP)$$

Classification of regimes

Regime 1
$CO_2 = 0.460*GDP + 0.012*t$, when $F(GDP) = 0$
Regime 2
$CO_2 = 0.358*GDP + 0.063*t$, when $F(GDP) = 1$

Location parameter	Smoothness	Asymmetry
$\hat{c} = 9.352$	$\hat{\gamma} = 22.81$	$\hat{k} = 0.2$
(190.6)	(3.573)	(.)

Implied threshold
$Y^{threshold} = 9.201$ (antilog \$9,912)

R-sq = 0.9646

Regime switching (STR) effect *p*-value

Regression 5 (*GDP* squared)	0.009
Regression 6 (*GDP* squared & cubed)	0.024

Notes: The model is estimated by NLS conditioning on the value of k. Since the joint estimation of γ and k turned out to be very difficult (the algorithm did not converge) we followed the recommendation in Teräsvirta (1994) and conditioned the NLS estimation on one of the parameters (e.g, k was set to the value of 0.2 which was obtained from the grid search). Values in parentheses are t-ratios. The model is estimated in logs.

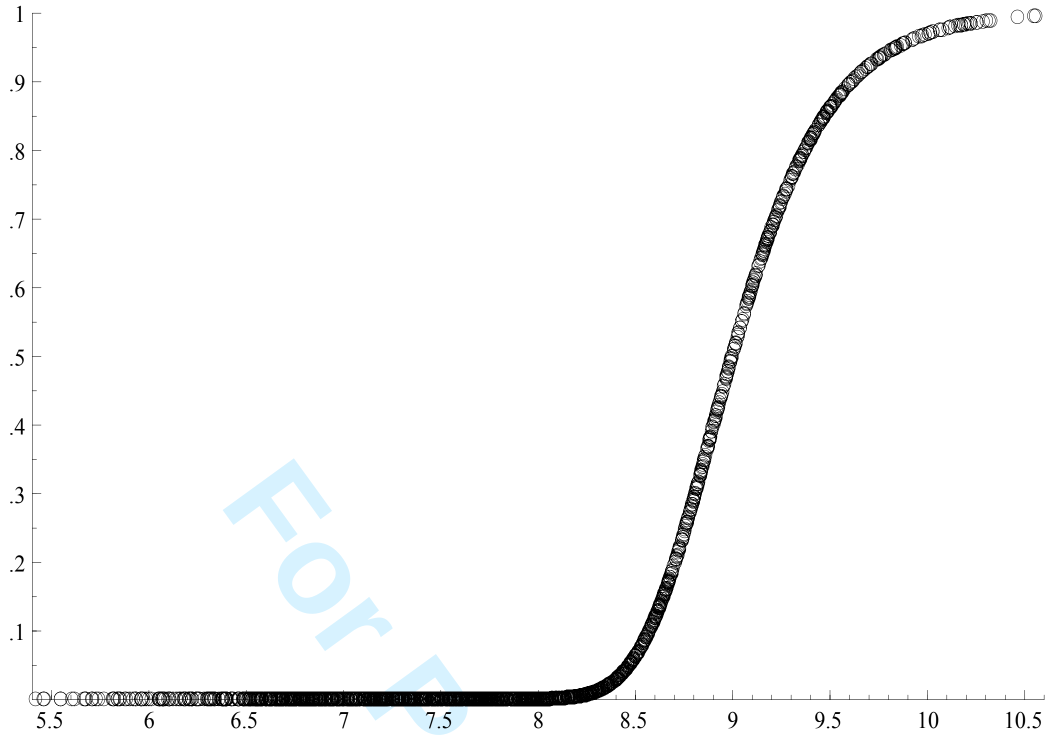

Figure 1: Transition function of the PSTR model for *CO*2 vs. *GDP* (in logarithms). All non-OECD countries.

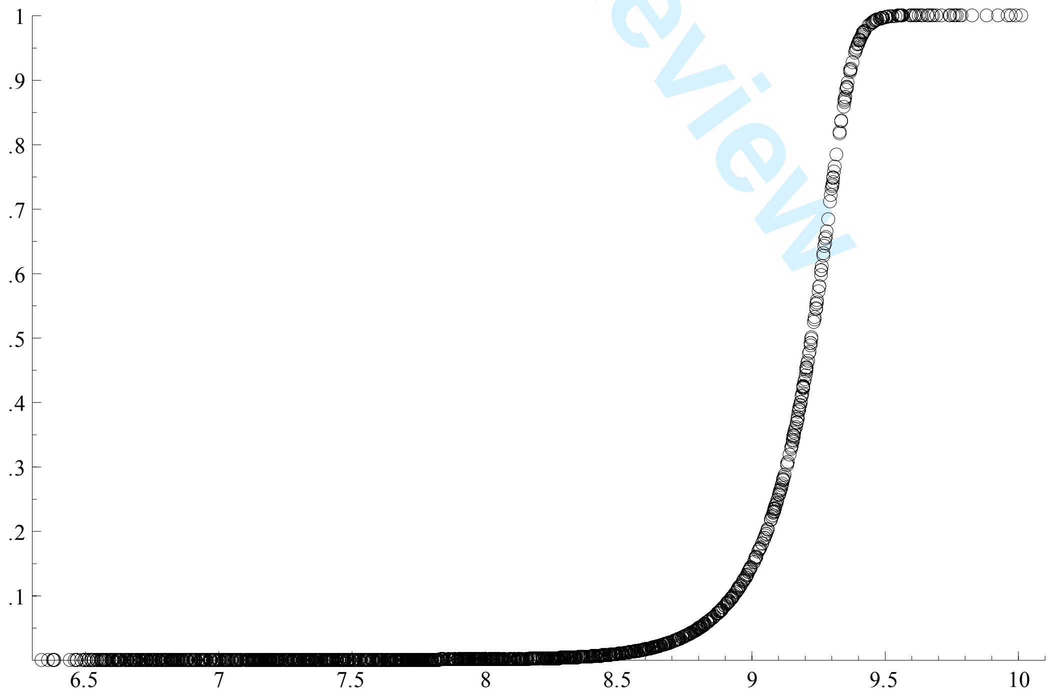

Figure 2: Transition function of the PSTR model for *CO*2 vs. *GDP* (in logarithms). Non-OECD countries excluding the 5% richest and the 5% poorest countries.